Astronomical Tides and Turbulent Mixing in ROMS/TOMS

Lakshmi Kantha
CB 429, University of Colorado, Boulder, CO 80309-0429
Phone: 303-492-3014 Fax: 303-492-2825 Email: kantha@colorado.edu

Grant Number: N00014-06-1-0287
http://ocean.colorado.edu/~kantha

LONG-TERM GOALS

The long-term goal of this effort is to improve the Navy community ocean circulation model ROMS/TOMS by incorporating astronomical tidal forcing and the latest developments in turbulent mixing.

OBJECTIVES

The principal objective of this research is to improve subgrid-scale parameterization in Navy community and operational ocean circulation models. This is to be accomplished by assessing and refining turbulent mixing parameterization as well as including comprehensive direct astronomical tidal forcing of importance to many semi-enclosed marginal seas.

APPROACH

This project complements extremely well, the AESOP program, the ONR DRI on subgrid-scale parameterization and skill assessment of numerical ocean models as well as the new Characterization and Modeling of Archipelago Strait Dynamics (CMASD) DRI. Using the Adriatic Sea ROMS/TOMS as the test bed, we will incorporate direct astronomical forcing of the 11 major tides in the global ocean: semidiurnal M2, S2. N2, K2; diurnal K1, O1, P1 and Q1; long period Mf, Mm and Ssa. The co-oscillating barotropic tides will be prescribed from LHK's tidal model of the Mediterranean Sea (see *ocean.colorado.edu/ ~kantha*). Note that many global ocean models such as the ones resulting from NASA initiatives do not perform well in some marginal seas and it is essential that a regional model be used. Note also that compound tides such as M4 will be generated by the nonlinear model itself and is an indirect result of the principal astronomical tidal forcing.

The latest *Kantha and Clayson* (2004) turbulent mixing model based on second moment closure will be incorporated into ROMS/TOMS. This model includes the effect of surface waves. No other turbulence model does at present. The inclusion of surface wave effects such as wave breaking and Stokes production should greatly improve the simulation of drifter trajectories in the Adriatic.

A very high-resolution version of ROMS/TOMS will be set up for the Venice Lagoon and will be driven at the boundary by the Adriatic Sea ROMS/TOMS. This will facilitate testing the skill of this model in shallow lagoon systems and is highly pertinent to the current focus of the ONR.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**
4. TITLE AND SUBTITLE **Astronomical Tides and Turbulent Mixing in ROMS/TOMS**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Colorado,CB 429,Boulder ,CO,80309-0429**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

WORK COMPLETED

Observational data to compare with turbulence models are scarce. Microstructure measurements have not become a routine staple of oceanographic measurements as CTD casts have been for decades. In collaboration with Dr. Sandro Carniel of ISMAR, Italy, who has a related NICOP grant from ONR, we have participated in NATO Undersea Research Center/Naval Research Laboratory (NURC/NRL) DART 06A and 06B cruises in March and August of this year, and collected turbulence data using a microstructure profiler (e.g. Figure 1). The five hundred and twenty microstructure profiles collected greatly enhance the turbulence database in the Adriatic, which consists of approximately 73 profiles collected by *Peters and Orlic* (2005) and *Peters et al.* (2006) in the Northern Adriatic. Along with other complementary oceanographic data collected during the cruises, these microstructure measurements provide a nice dataset to assess turbulent mixing parameterization in ROMS/TOMS. See *Carniel et al.* (2006) for more details.

This project started in February 22nd of this year and already we have made considerable progress in the modeling arena. With the help of our Italian and American colleagues, the ROMS/TOMS model has been successfully ported to our Sun workstation, configured for the Adriatic Sea and numerous runs have been made. The version we are running incorporates General Ocean Turbulence Model (GOTM) developed by EU Turbulence researchers, thanks to Dr. John Warner of USGS. This provides a good framework for making modifications to the turbulent mixing parameterization in ROMS. For example, we have included non-local mixing and Stokes production effects into the LMD mixed layer model component of ROMS and have investigated the resulting differences.

The upcoming tasks for this year include assessment and refinement of turbulence parameterization in ROMS/TOMS by comparison with DART data. The latest *Kantha and Clayson* (2004) turbulent mixing model based on second moment closure will be incorporated into ROMS/TOMS.

We will work on incorporating astronomical tidal forcing into ROMS/TOMS in the coming year. Using the Adriatic Sea ROMS/TOMS as the test bed, we will incorporate direct astronomical forcing of the 11 major tides in the global ocean: semidiurnal M2, S2. N2, K2; diurnal K1, O1, P1 and Q1; long period Mf, Mm and Ssa. The co-oscillating barotropic tides will be prescribed from LHK's tidal model of the Mediterranean Sea (see *ocean.colorado.edu/ ~kantha*).

RESULTS

A destabilizing buoyancy flux at the ocean surface leads to convective mixing in the water column. Under pure convection, the TKE dissipation rate ε must simply scale as the surface buoyancy flux *Jb0*. It has been the practice hitherto, following *Shay and Gregg* (1984, 1986), *Lombardo and Gregg* (1989) and *Brainerd and Gregg* (1993 a&b) to assume that the dissipation rate $\varepsilon \sim cJ_{b0}$ is constant in the entire mixed layer under pure convection (e.g. *Peters et al.* 1988, 2006). The value of the constant is taken as ~0.58 following *Lombardo and Gregg* (1989). However, *Carniel et al.* (2006) show that a more reasonable value for *c* to be 0.39. Therefore, in the convective mixed layer

$$\begin{aligned} \varepsilon_c &= J_{b0} && z = 0 \\ &= 0.39 J_{b0} && 0.1D \le z \le 0.9D \\ &= 0 && z \ge D. \end{aligned} \qquad (1)$$

On the other hand, when the turbulence in the mixed layer is mechanically driven, by the wind stress, the law of the wall demands that the dissipation rate near the surface follow the relationship $\varepsilon = u_*^3/(\kappa z)$, where κ is the von Karman constant, $u*$ is the friction velocity and z is the distance from the surface. This similarity relationship should hold in the upper few meters near the surface if we ignore the wave effects on ε scaling. The falling microstructure probe did not allow us to make measurements in the upper 2-3 m, where the influence of surface waves on the TKE dissipation rate is most prominent. *Carniel et al.* (2006) show that in the wind stress-driven mixed layer,

$$\begin{aligned} \varepsilon_s &= u_*^3/(\kappa z) && 0 \le z \le 0.3D \\ &= 3.33 u_*^3/(\kappa D) && 0.3D < z \le D \\ &= 0 && z > D. \end{aligned} \tag{2}$$

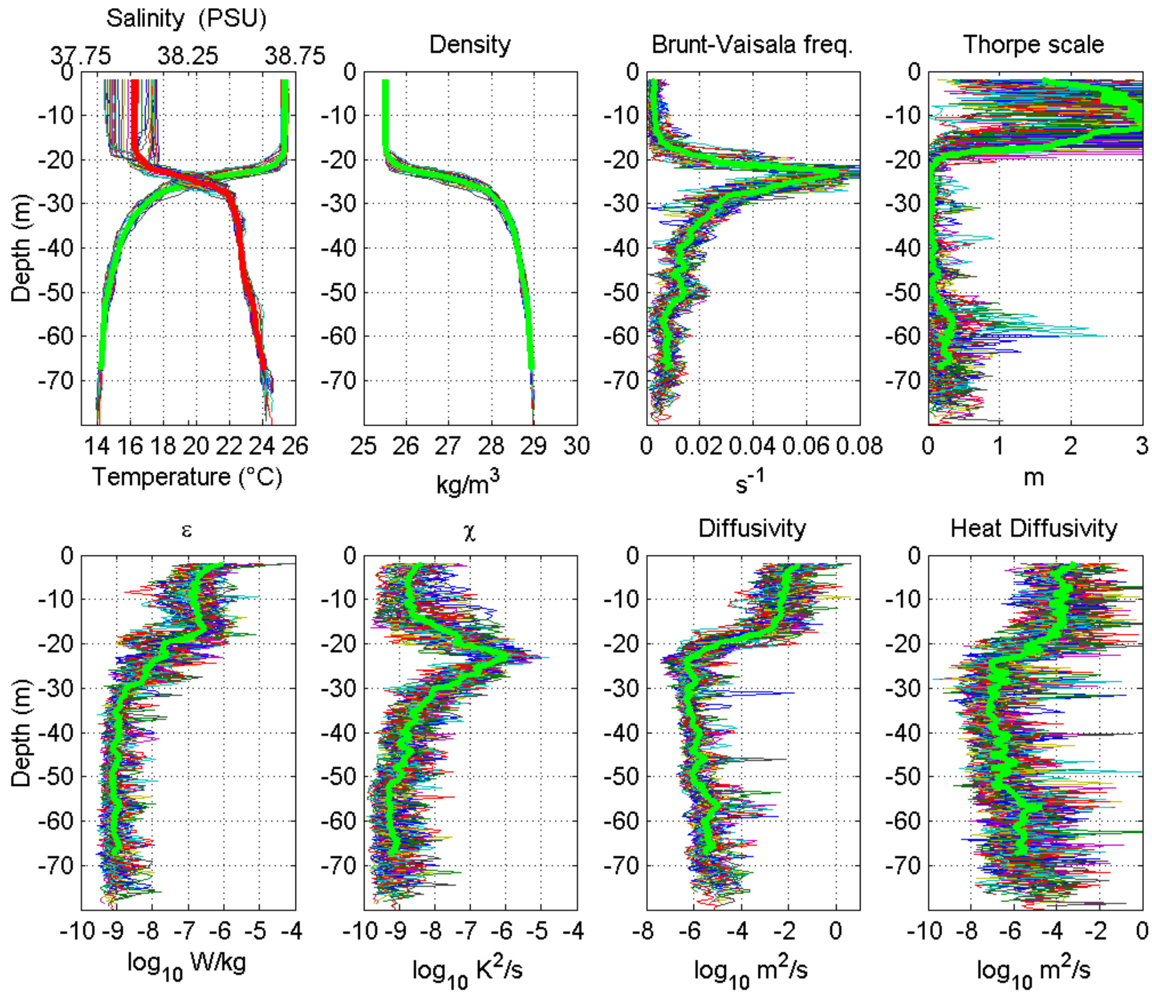

Figure 1: Profiles of temperature (°C) and salinity (psu), density (kg m-3) and buoyancy frequency (s-1), and the Thorpe scale (top panels), TKE dissipation rate (W kg-1), temperature variance dissipation rate (K2 s-1), eddy diffusivity K (m2s-1), and the heat diffusivity Kh (m2s-1) (bottom panels) as measured during OP B90-4 at Station B90 in the Gulf of Manfredonia, under moderate winds and nocturnal cooling. A total of 32 casts were made over 2.5 hr centered around the midnight of August 24th/25th. The green line denotes the corresponding average value. The slow change in salinity during the OP is due to the ship drifting over a patch of brackish water. Thick redline in panel 1 shows mean salinity.

Below the mixed layer and in the interior of the water column, mixing is episodic and internal wave field-driven. The relevant length scale is the Ozmidov length scale

$$L_O = \sqrt{\frac{\varepsilon}{N^3}} \tag{3}$$

If we further assume that the Thorpe scale *LT* (*Thorpe* 1977) is proportional to the Ozmidov scale *LO* (e.g., *Dillon*, 1982; *Stansfield et al.*, 2001), the dissipation rate can be taken to be

$$\varepsilon_i = 0.03 L_T^2 N^3 \tag{4}$$

where the proportionality constant has been determined by the best fit to values appropriate to the observed background dissipation rate deep in the water column (depth ~ 60-80m).

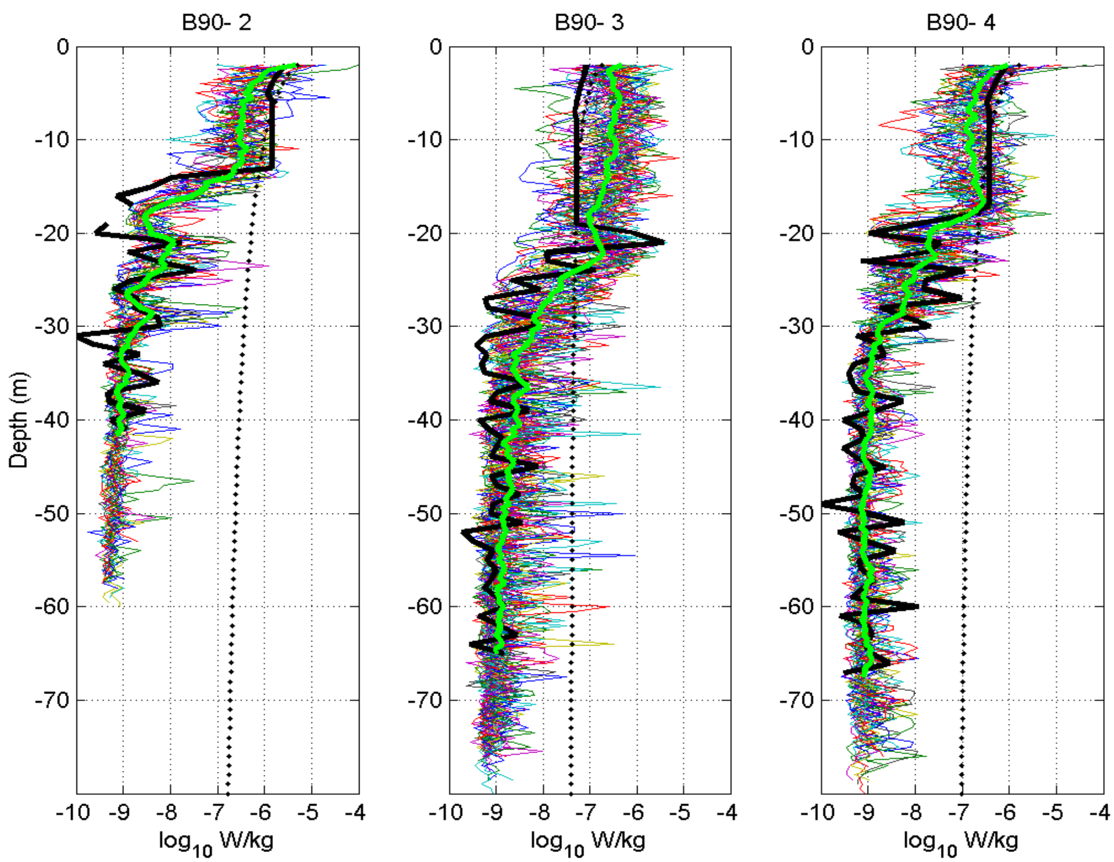

Figure 2. Observed dissipation rates observed at Station B90 compared with theoretical scaling for OPs B90-2, B90-3 and B90-4: thick black line (Eq. 5), black dotted line (Eq. 6), and green line (observational mean).

When the turbulence is generated by both the momentum flux and a destabilizing buoyancy flux, the TKE dissipation rate ε in the mixed layer can be taken to be the sum of the rates due to shear-driven and buoyancy-driven turbulence. Therefore

$$
\begin{aligned}
\varepsilon &= \varepsilon_c + \varepsilon_s \qquad z \le D \\
&= \varepsilon_i \qquad\qquad z > D
\end{aligned} \tag{5}
$$

Figure 2 shows the TKE dissipation rate profiles plotted along with the profile indicated by Eq. (5) for OPs B90-2, B90-3 and B90-4. The conventional scaling (*Lombardo and Gregg* 1989, *Brainerd and Gregg* 1993 a&b, *Stips et al*. 2002)

$$
\begin{aligned}
&\varepsilon_c = 0.58 J_{b0};\ \ \varepsilon_s = 1.76 u_*^3/(\kappa z) \\
&\varepsilon = \varepsilon_c + \varepsilon_s
\end{aligned} \tag{6}
$$

is also shown. It can be seen that Eq. (5) is a better depiction of the dissipation rates in the deep than the traditional formulation (Eq. 6), which has no validity below the upper mixed layer and hence should not be applied except in the mixed layer. In the mixed layer itself, the difference between the two formulations is small, although Eq. (5) is better justified from first principles. The disagreement between the theoretical formulations and the observed values is undoubtedly due to inaccuracies in inferring $Jb0$ and $u*$ from bulk formulae.

IMPACT/APPLICATIONS

Accurate depiction of many quantities of interest to worldwide naval operations, such as the upper layer temperature and currents, requires accurate simulation of turbulent mixing in the water column and accurate tidal forcing. Operationally, this contributes to better counter mine warfare capabilities through better and more accurate tracking of drifting objects such as floating mines. Other drifting materials such as spilled oil are also better tracked and counter measures made more effective. Other applications include search and rescue.

RELATED PROJECTS

1. Subgrid-scale Parameterization in 3-D Ocean Models: The Role of Turbulent Mixing (PI - Dr. Sandro Carniel of ISMAR, Venice, Italy) – NICOP.

2. Improving the Skill of Ocean Mixed Layer Models (PI - L. Kantha) – N00014-05-1-0759. Ended June 2006.

REFERENCES

Brainerd, K. E., and M. C. Gregg (1993a). Diurnal restratification and turbulence in the oceanic mixed layer, 1, Observations, *J. Geophys. Res., 98,* 22,645-22,656.

Brainerd, K. E., and M. C. Gregg (1993b). Diurnal restratification and turbulence in the oceanic mixed layer, 2, Modeling, *J. Geophys. Res., 98,* 22,657-22,666.

Carniel, S., L. Kantha, H. Prandke, J. Chiggiato, and M. Sclavo (2006) Turbulence in the Upper Layers of the Southern Adriatic Sea Under Various Meteorological Conditions During Summer 2006. *J. Geophys. Res.* (submitted).

Dillon, T.M., (1982). Vertical overturns: a comparison of Thorpe and Ozmidov length scales. *J. Geophys. Res. 85*, 9601-9613.

Dillon, T. M., J. G. Richman, C. G. Hansen, and M. D. Pearson (1981). Near-surface turbulence measurements in a lake, *Nature, 290,* 390-392.

Kantha, L. and C. A. Clayson, 2004. On the effect of surface gravity waves on mixing in an oceanic mixed layer, *Ocean Modelling,* 6, 101-124.

Lombardo, C. P., and M. C. Gregg (1989). Similarity scaling of viscous and thermal dissipation in a convecting surface boundary layer, *J. Geophys. Res., 94,* 6273-6284.

Peters, H., and M. Orlic (2005). Ocean mixing in the springtime central Adriatic Sea, *Geofizika 22,* (in press).

Peters, H., M. C. Gregg, and J. M. Toole (1988). On the parameterization of equatorial turbulence, *J. Geophys. Res., 93,* 1199-1218.

Peters, H., M. C. Gregg, and J. M. Toole (1989). Meridional variability of turbulence through the equatorial undercurrent, *J. Geophys. Res., 94,* 18,003-18,009.

Peters, H., C. M. Lee, M. Orlic and C. E. Dorman (2006). Turbulence in the wintertime northern Adriatic Sea under strong atmospheric forcing, *J. Geophys. Res.,* (submitted)

Shay, T. J., and M. C. Gregg (1984). Turbulence in an oceanic convective mixed layer. *Nature, 310,* 282-285.

Shay, T. J., and M. C. Gregg (1986). Convectively driven turbulent mixing in the upper ocean. *J. Phys. Oceanogr., 16,* 1777-1798.

Stansfield, K., C. Garret, and R.K. Dewey, (2001). The probability distribution of the Thorpe displacement with overturns in the Juan de Fuca Strait. *J. Phys. Oceanogr. 32*, 3421-3434.

Stips, A., H. Burchard, K. Balding and W. Eifler (2002). Modelling of convective turbulence with two-equation k-e turbulence closure scheme. *Ocean Dyn*., 52, 153-168.

Thorpe, A.S. (1977). Turbulence and mixing in a Scottish Loch. *Phil. Trans. Roy. Soc. London, Ser. A 286*, 125-181.

PUBLICATIONS

1. Carniel, S., L. Kantha, H. Prandke, J. Chiggiato, and M. Sclavo (2006) Turbulence in the Upper Layers of the Southern Adriatic Sea Under Various Meteorological Conditions During Summer 2006. *J. Geophys. Res.* (submitted).

2. Carniel, S., L. Kantha, H. Prandke, M. Rixen, and J. Book (2006) Turbulence Measurements Across a Coastal Front in the Southern Adriatic Sea during Spring 2006 (under preparation).